CHAPTER IX

IX TROPHIC STATUS AND PERMISSIBLE LOADINGS

A. Introduction

The trophic status of a waterbody is a hybrid concept referring to the nutritive state (especially phosphorus) of a lake or pond, but is often described in terms of biological activity that occurs as a result of nutrient levels. Trophic state indices have been developed both on the use of a single parameter and on the use of several parameters.

Table IX-1, reproduced in part from the EPA Clean Lakes Program Guidance Manual (1980), describes the lake water characteristics of the oligotrophic and eutrophic states. Mesotrophic conditions exist between the limits for eutrophy and oligotrophy.

Table IX-1

Summary of Quantitative Definitions of Lake Trophic Status

Characteristics	Oligotrophy	Eutrophy
Total phosphorus (ug/L, winter)	$\leq$ (10 to 15)	$\geq$ (20 to 30)
Chlorophyll-*a* (ug/L, summer)	$\leq$ (2 to 4)	$\geq$ (6 to 10)
Secchi disk depth (m, summer)	$\geq$ (3 to 5)	$\leq$ (1.5 to 2)

This chapter will examine several trophic classification and permissible loading schemes.

B. Trophic Classification Schemes

1. State of New Hampshire Trophic Classification System

The classification system developed by the Biology Bureau of the New Hampshire Water Supply and Pollution Control Division (Table IX-2) utilizes four parameters (Towne and Estabrook, 1981). Table IX-3 lists for Webster Lake, the calculated value of each classified parameter for the 1979 survey and 1988 study year, the trophic points received and the trophic status.

Table IX-2

TROPHIC CLASSIFICATION SYSTEM
FOR
NEW HAMPSHIRE LAKES AND PONDS

	TROPHIC POINTS
1. Summer Bottom Dissolved Oxygen:	
a. D.O. ≥ 5mg/l	0
b. 2mg/l ≤ D.O. < 5mg/l & <30 foot depth	1
c. 2mg/l ≤ D.O. < 5mg/l & ≥30 foot depth	2
d. .5mg/l ≤ D.O. <2mg/l & <30 foot depth	3
e. .5mg/l ≤ D.O. <2mg/l & ≥30 foot depth	4
f. D.O. <.5mg/l & <30 foot depth	5
g. D.O. <.5mg/l & ≥30 foot depth	6
2. Summer Secchi Disk Transparency:	
a. > 24 feet	0
b. > 12 feet to 24 feet	1
c. > 6 feet to 12 feet	2
d. > 3 feet to 6 feet	3
e. > 1 foot to 3 feet	4
f. > .5 foot to 1 foot	5
g. ≤ .5 foot	6
3. Aquatic Vascular Plant Abundance:	
a. Sparse	0
b. Scattered	1
c. Common	2
d. Abundant	3
e. Very abundant	4
4. Summer Epilimnetic Chlorophyl *a* (mg/M^3):	
a. Chl *a* <5	0
b. 5 ≤ Chl *a* <10	1
c. 10 ≤ Chl *a* <20	3
d. Chl *a* ≥ 20	5

TROPHIC CLASSIFICATION	TROPHIC POINTS STRATIFIED	TROPHIC POINTS *UNSTRATIFIED
Oligotrophic	0-5	0-3
Mesotrophic	6-10	4-6
Eutrophic	11-21	7-15

*Unstratified lakes are not evaluated by the bottom dissolved oxygen criterion.

Table IX-3

Trophic Classification of Webster Lake

Trophic Classification - 1979 Survey

Parameter	Value	Trophic Points
Dissolved Oxygen	0.5 mg/L	4
Secchi Disk	3.0 m	2
Plant Abundance	Sparse	0
Chlorophyll-a	3.99 mg/m^3	0
	Total	6

Trophic Classification - 1988 Study Year

Parameter	Value	Trophic Points
Dissolved Oxygen	0.0 mg/L	6
Secchi Disk	*4.1 m	1
Plant Abundance	Sparse	0
Chlorophyll-a	*6.1 mg/m^3	1
	Total	8

Revised Trophic Classification

Method - 1988 Study Year

Parameter	Value	Trophic Points
Dissolved Oxygen	0.0 mg/L	4
Secchi Disk	*4.1 m	2
Plant Abundance	Sparse	0
Chlorophyll-a	*6.1 mg/m^3	1
	Total	7

*Median Value

Webster Lake received a total of 6 trophic points in 1979 while in 1988 it received 8 points. The additional points resulted from a decrease in bottom dissolved oxygen concentration and an increase in chlorophyll-a concentrations. Webster Lake's trophic classification did not change from its 1979 mesotrophic rating. It did however, decline from a borderline mesotrophic/oligotrophic to a firm mesotrophic rating.

The system used to trophically classify New Hampshire lakes and ponds was revised in 1989 (Table IX-4). The purpose of the revision was to provide for equal points under each attribute and to reduce the impact of the bottom dissolved oxygen criterion. Unlike the previous system, the extent of oxygen depletion is evaluated in the new system.

Webster Lake is re-classified (Table IX-3) using the revised trophic classification method and the data collected during the 1988 study year. Utilizing the revised method, Webster Lake remained mesotrophic (Tables IX-3 and IX-4).

2. Carlson Trophic State Index

Carlson's (1974) TSI system is based upon Secchi depth as a means of characterizing algal biomass. This parameter, in the absence of turbidity and colored materials in water, is a direct measure of "plankton-algal-manifested eutrophication processes" in natural waters. Its range of values can easily be transformed into a convenient scale. Further, by using empirically derived relationships between Secchi depth and both phosphorus and chlorophyll-a concentration, Carlson has derived equations to estimate the same index value from these two parameters as well as from Secchi depth. Carlson's trophic index is basically a linear transformation of Secchi depth, such that each major unit in his scale has half the value of the next lowest unit. Conversely, for total phosphorus and chlorophyll-a, each major unit in his scale has larger values for the next higher unit. The computational form of the equations for his trophic scheme is as follows:

$$TSI_{(SD)} = 10\ (6 - \log_2 SD),$$

$$TSI_{(TP)} = 10\ (6 - \log_2 48\ \frac{1}{TP}),\ \text{and}$$

$$TSI_{(Chl\underline{a})} = 10\ (6 - \log 27.7\ \frac{1}{Chl\underline{a}\ 0.68})$$

Table IX-4

Trophic Classification System for New Hampshire Lakes and Ponds (Revised 1989)

	TROPHIC POINTS
1. Summer Bottom Dissolved Oxygen (mg/L):	
a. D.O. >4 mg/L	0
b. D.O. = 1 to 4 mg/L & hypo. vol. ≤ 10% lake vol	1
c. D.O. = 1 to 4 mg/L & hypo. vol. > 10% lake vol	2
d. D.O. <1 mg/L in <1/3 hypo. vol. & hypo. vol. ≤ 10% lake vol.	3
e. D.O. <1 mg/L in ≥1/3 hypo. vol. & hypo. vol. ≤ 10% lake vol.	4
f. D.O. <1 mg/L in <1/3 hypo. vol. & hypo. vol. > 10% lake vol.	5
g. D.O. <1 mg/L in ≥1/3 hypo. vol. & hypo. vol. > 10% lake vol.	6
2. Summer Secchi Disk Transparency (M):	
a. >7m	0
b. >5m - 7m	1
c. >3m - 5m	2
d. >2m - 3m	3
e. >1m - 2m	4
f. >.5m -1m	5
g. ≤.5m	6
3. Summer Vascular Aquatic Plant Abundance:	
a. Sparse	0
b. Scattered	1
c. Scattered/Common	2
d. Common	3
e. Common/Abundant	4
f. Abundant	5
g. Very Abundant	6
4. Summer Epilimnetic Chlorophyll a (mg/m^3):	
a. < 4	0
b. 4 - < 8	1
c. 8 - < 12	2
d. 12 - < 18	3
e. 18 - < 24	4
f. 24 - < 32	5
g. ≥32	6

TROPHIC CLASSIFICATION	TROPHIC POINTS STRATIFIED	TROPHIC POINTS *UNSTRATIFIED
Oligotrophic	0 - 6	0 - 4
Mesotrophic	7 - 12	5 - 9
Eutrophic	13 - 24	10 - 18

*Lakes with no hypolimnion are not evaluated by the bottom dissolved oxygen criterion.

where

SD = Secchi depth (m)

TP = Total phosphorus concentration (mg/M^3) and

Chl-a = Chlorophyll-a concentration (mg/M^3)

According to Carlson (1974), this index system has the advantages of easily obtained data, simplicity of form (i.e. trophic condition reported as a single number), objectivity, absolute TSI values, valid relationships, retrieval of data from the index, and can be grasped by the layman in much the same manner as the Richter earthquake scale. The TSI incorporates most lakes in a scale of 0 to 100 as Figure IX-1 demonstrates. Each major division (10, 20, 30, etc.) represent a doubling of algal biomass.

Results of the Carlson TSI were obtained by substituting summer mean Secchi depth, chlorophyll-a, and phosphorus values, from Webster Lake, into the equations to compute the TSI. Table IX-5 shows the mean summer values, the TSI number and the classification for each measured parameter. The chlorophyll-a value observed at Webster Lake reflects moderate concentrations that would be observed in a mesotrophic lake or pond. Median Secchi disk observations are representative of borderline mesotrophic/oligotrophic conditions. An examination of mean summer in-lake phosphorus concentrations, for each stratification layer, show a Carlson ranking of borderline mesotrophic/oligotrophic for the epilimnion, oligotrophic for the metalimnion and mesotrophc for the hypolimnion.

Table IX-5
Carlson Trophic Classification
for Webster Lake

Parameter	Mean Summer Value	Trophic Points	Classification
Chlorophyll-a (mg/m^3)	4.55	44	Mesotrophic
Secchi Disk (m)	4.5	39	Mesotrophic/ Oligotrophic
Phosphorus (ug/L)	Epi. 9.7	38	Mesotrophic/ Oligotrophic
	Meta. 7.7	35	Oligotrophic
	Hypo. 20.3	45	Mesotrophic

Carlson's Trophic State Index

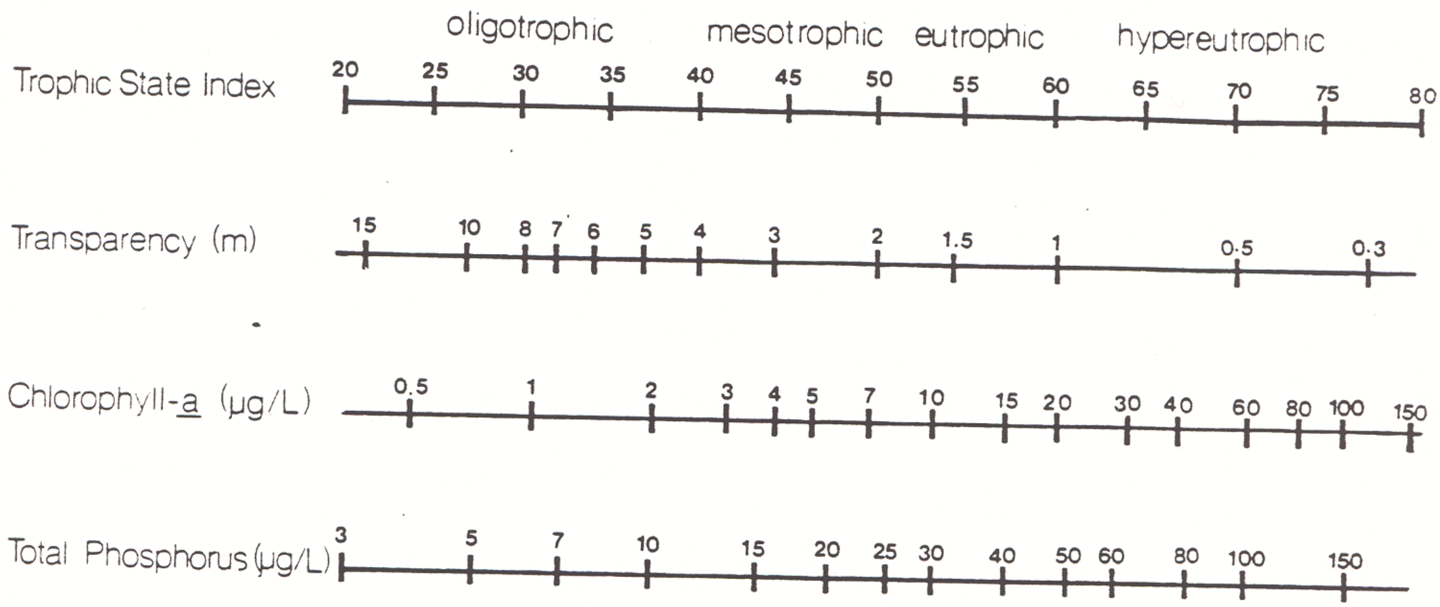


Figure IX-1. Carlson's Trophic State Index Scale.

3. Dillon & Rigler Permissible Loading Model

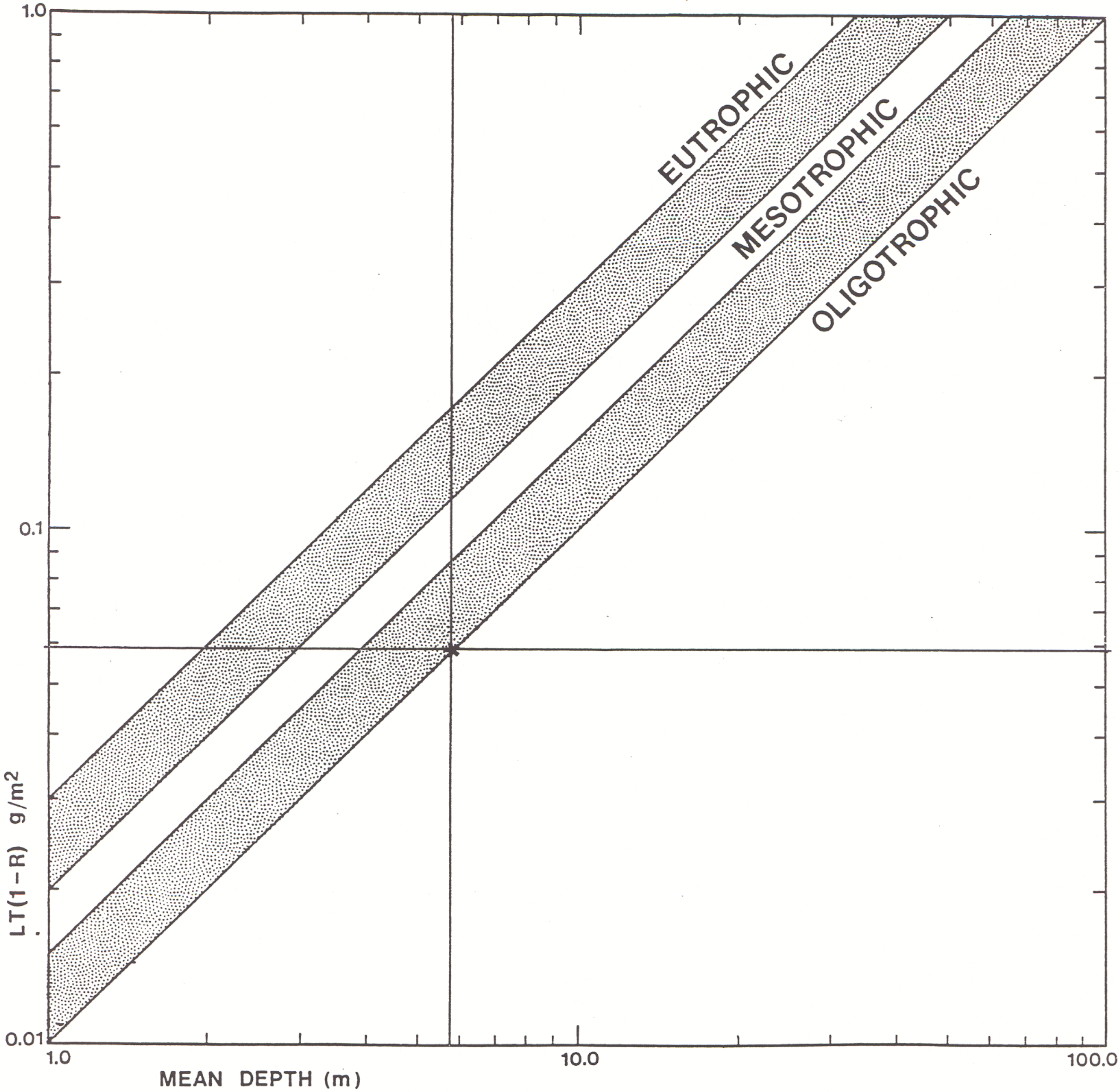
Mathematical models can also be useful both in diagnosing lake problems and evaluating potential solutions. They represent in quantitative terms the cause-effect relationships that determine lake water quality. In some cases, the determination of the trophic state of a lake involves a comparison of actual phosphorus loading to the lake with a maximum permissible loading that the lake can tolerate before excessive weed and algae growth occurs and transparency diminishes. The trophic model developed by Dillon-Rigler (1975) has been widely utilized and well documented by researchers. Its application classifies a lake as oligotrophic, mesotrophic or eutrophic by comparing calculated actual loadings with permissible annual loadings. The tolerance of the lake to phosphorus loading is predicted as a function of two morphological parameters, mean depth (z) and water retention time (T), which have been proven by several researchers to be the primary determinants of loading permissibility. Additionally, the model considers the phosphorus retention in the lake sediments. The retention coefficient (R) may be empirically calculated from morphological data or may be derived from a definitive phosphorus budget.

Table IX-6 shows the qualitative relationship between the model input parameters and phosphorus loading tolerance.

Table IX-6
Phosphorus Loading Tolerance

High Phosphorus Loading Tolerance	Low Phosphorus Loading Tolerance
*Large mean water depth	*Small mean water depth
*Rapid flushing rate	*Slow flushing rate
*High sediment retention	*Low sediment retention

Thus, existing trophic status is set by existing values for these parameters and annual phosphorus loading. Similarly, historical trophic status can be determined from estimates of previous phosphorus loading. The degree of trophic state improvement, which would result from the implementation of watershed and in-lake management strategies, can be gauged from predicted changes of loading and morphology. Figure IX-2 is a graphical representation of the Dillon-Rigler model showing trophic zones, plotted on axes of mean depth and areal loading, with the data point for the Webster Lake normalized year.



L = AREAL PHOSPHORUS LOADING ($g/m^2/yr$)
R = PHOSPHORUS RETENTION COEFFICIENT (DIMENSIONLESS)
T = HYDRAULIC RETENTION TIME (yr)

FIGURE IX-2. DILLON / RIGLER TROPHIC STATUS FOR WEBSTER LAKE

The solution of the Dillon-Rigler equation for Webster Lake data (unaltered morphology) shows the existing oligotrophic/mesotrophic boundary to exist between 604 and 911 $kgPyr^{-1}$ and the mesotrophic/eutrophic boundary to exist between 1271 and 1905 $kgPyr^{-1}$. These boundaries for loadings are based on a mean depth (z) of 5.7 m, a water retention time (T) of 0.52 yr and a phosphorus retention coefficient (R), derived from the phosphorus budget, of 0.55. The budgeted phosphorus loading for the normalized year at Webster Lake was 619 $kgPyr^{-1}$, which classifies the lake as borderline mesotrophic/oligotrophic.

The Dillon-Rigler model demonstrates that a loading reduction of 15 $kgPyr^{-1}$ would elevate Webster Lake into the oligotrophic classification range.

The Dillon-Rigler model also predicts in-lake phosphorus concentrations. Utilizing the Dillon-Rigler equation $P=Lp/qs(1-R)$, the calculated predicted in-lake phosphorus concentration for Webster Lake was 0.010 mg/L. This predicted value compares favorably with an actual mean epilimnetic phosphorus concentration of 0.014 mg/L. The actual mean epilimnetic phosphorus concentrations were calculated from three years of data collected by the Biology Bureau and monitors from the New Hampshire Volunteer Lake Assessment Program, between 1986 and 1989.

4 Vollenweider Phosphorus Loading and Surface Overflow Rate Relationship

The Vollenweider model is based on a five year study involving the examination of phosphorus load and response characteristics for about 200 waterbodies in 22 countries in Western Europe, North America, Japan and Australia. Vollenweider, working on the organization for Economic Cooperation and Development (OECD) Eutrophication Study, developed a model describing the relationship of phosphorus load and the relative general acceptability of the water for recreational use (Vollenweider, 1975). Vollenweider found that when the annual phosphorus load to a lake is plotted as a function of the quotient of the mean depth and hydraulic residence time, lakes which were eutrophic tended to cluster in one area and oligotrophic lakes in another (Figure IX-3, from Flanders, 1986).

Vollenweider developed a statistical relationship between areal annual phosphorus loading to a lake normalized by mean depth (2) and hydraulic residence time (T), to predict phosphorus lake concentration. Table IX-7 summarizes the Vollenweider model parameters for the Webster Lake normalized year.

OECD DATA / VOLLENWEIDER PLOT

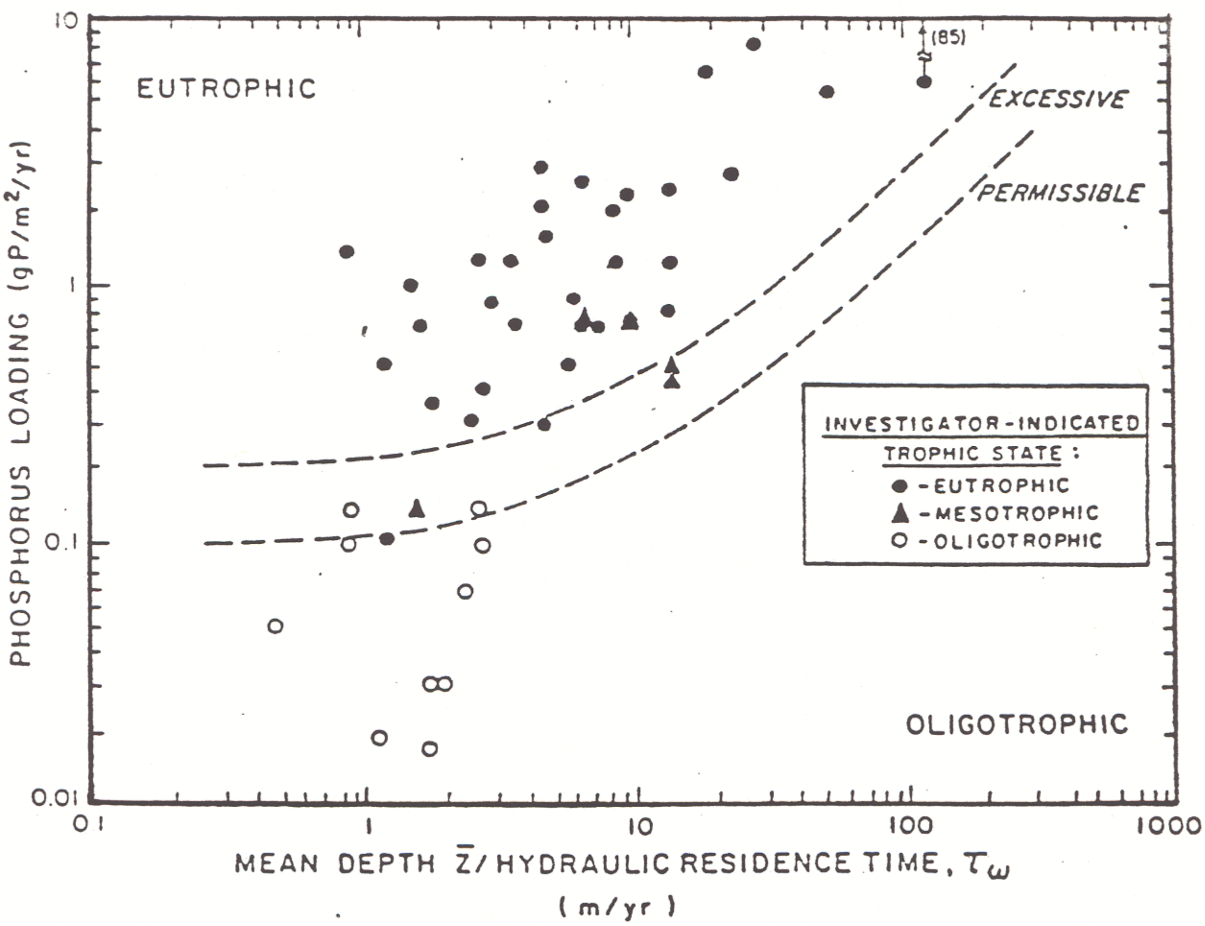


Figure IX-3. OECD Data and the Vollenweider Plot.

Table IX-7

Vollenweider Phosphorus Concentration Prediction

Parameter	Equation	Webster Lake
1. Hydraulic residence time T	T=V/Q	0.52
2. Surface overflow rate (qs)	qs=z/T	10.96
3. Areal phosphorus loading (LP)	P load/lake surface area	0.25 $g/m^2/yr$
4. Phosphorus concentration prediction	(Lp/qs) [1/(1+ z/qs)]	0.013 mg/L

Thus, based on the physical constraints that control water volume, the hydraulic residence time in the lake, and mean lake depth, combined with phosphorus loading, the Vollenweider model predicts the existing in-lake phosphorus concentration to be 0.013 mg/L in Webster Lake. An examination of actual mean epilimnetic in-lake phosphorus concentrations during the 1986-1988 study period, revealed that the actual concentration of 0.014 mg/L compared very favorably with the in-lake concentration predicted by the Vollenweider model.

Figure IX-4 graphically portrays the measured loading rates for Webster Lake and compares the lake with other studied lakes in New Hampshire. Based on the permissible and excessive loading curves, it can be seen that Webster Lake lies in the mesotrophic/oligotrophic boundry zone near the permissible loading range.

C. Trophic Classification Summary

A summary of the four classification schemes utilized in this study (Table IX-8) shows that the New Hampshire Lake classification system classifies Webster Lake as mesotrophic. The Dillon-Rigler model and Vollenweider Phosphorus Loading model classifies Webster Lake as borderline mesotrophic/oligotrophic. The Carlson Trophic Status Index defines a trophic class for several parameters. Chlorophyll-a measurements in Webster Lake fell into the mesotrophic range, while transparency measurements and phosphorus concentrations were in the mesotrophic/oligotrophic range.

On a permissible loading basis, the Dillon-Rigler model demonstrates that an improved trophic status is obtainable in Webster Lake, with modest reductions of phosphorus loading.

D. Predicting the Capacity of Webster Lake for Development

New Hampshire has experienced significant growth and development in the last two decades and is likely to continue to see such growth into the 1990's. This growth has greatly increased pressures on one of the very features that has attracted people to the state -- the lakes. While new development, both year-round and seasonal, and conversion/expansion of existing development allow more people to enjoy these resources, it also can threaten the quality of a lake environment.

VOLLENWEIDER PHOSPHORUS LOADING AND SURFACE OVERFLOW RATE RELATIONSHIP

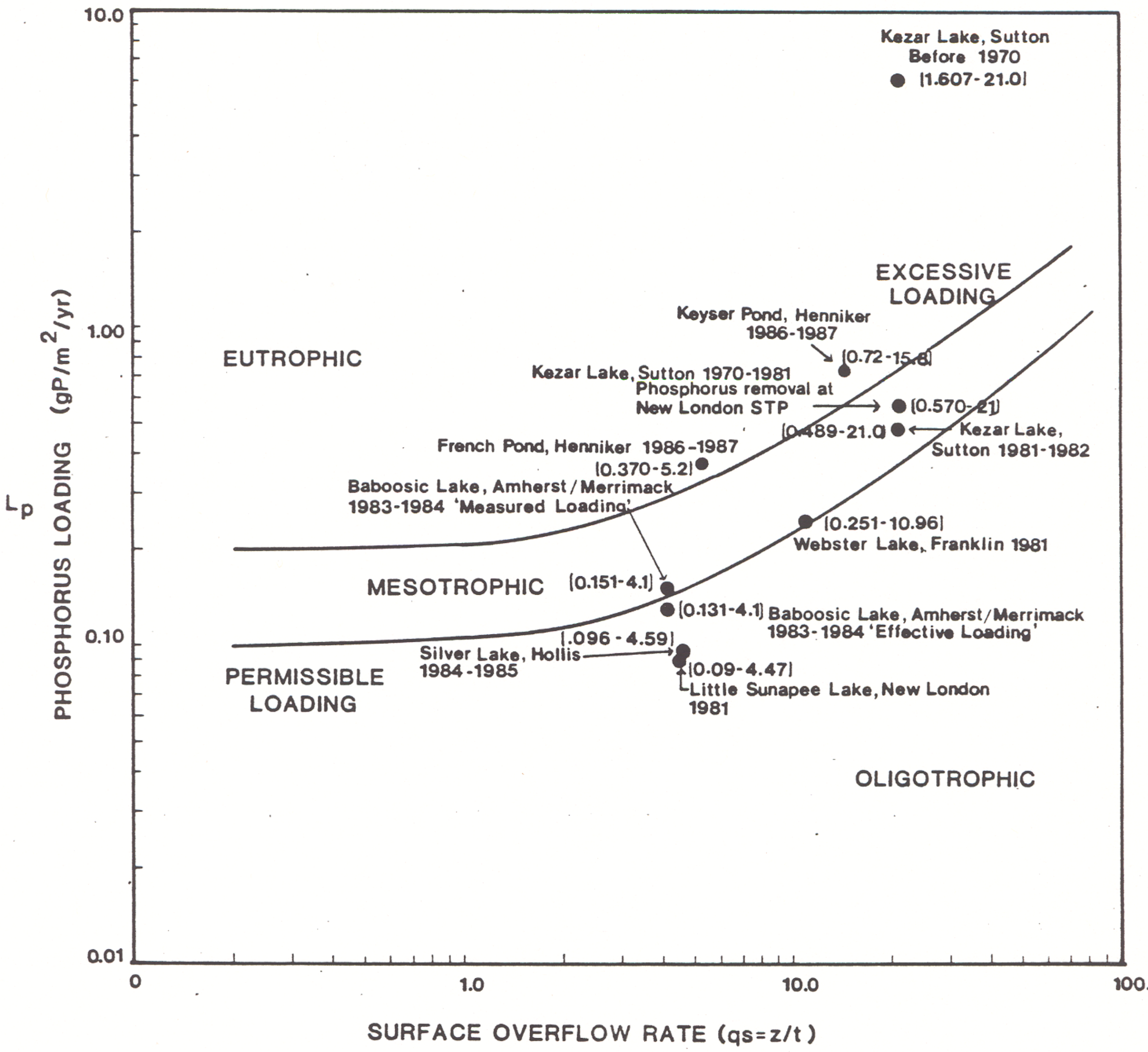


Figure IX-4. Vollenweider Phosphorus Loading and Surface Overflow Rate Relationship.

Table IX-8

Trophic Classification Summary

Classification Model	Trophic Classification
	Webster Lake
New Hampshire Lake Classification	Mesotrophic/Oligotrophic
Carlson's TSI	
Chlorophyll-a	Mesotrophic
Secchi disk	Mesotrophic/Oligotrophic
Phosphorus (Epilimnion)	Mesotrophic/Oligotrophic
Phosphorus (Hypolimnion)	Mesotrophic
Dillon/Rigler	Mesotrophic/Oligotrophic
Vollenweider	Mesotrophic/Oligotrophic

A predictive computer model has been utilized to aid in quantifying the environmental impacts of development on a lake. This model, which measures the phosphorus loading to a lake resulting from the surrounding development, predicts the capacity of the lake for seasonal and/or permanent development that will not threaten existing lake quality. Utilizing available data on the particular lake of interest and relying on several conservative assumptions about phosphorus impacts from certain kinds of development, the model presents the results in the form of a maximum number of allowable units of development around the lake. This number is intended as a guide for local officials in evaluating the impacts of proposed development on lakes.

Phosphorus (P) is the nutrient most frequently controlling lake productivity and, therefore, trophic status in New Hampshire lakes. Therefore, predictions concerning the impact of development on the phosphorus concentration of a lake, and subsequently on parameters describing the trophic state, are central to a predictive management scheme. From the geology and land use considerations of a lake's drainage basin, it is possible to estimate the total phosphorus exported or washed out per unit area of watershed. When combined with the drainage area, this provides an estimate of the total phosphorus supplied to the lake from the land. The addition of phosphorus input from direct lake precipitation determines the natural phosphorus load to the lake. Existing development--both year-round and seasonal--is then measured (tax maps or field counts with the assistance of local officials), and the phosphorus loading from artificial sources is calculated with the assistance of certain coefficients and conservative assumptions. The total P loading, natural plus artificial, may then be combined with the lake morphometry (general physical characteristics--size, depth, etc.) and water budget to predict a phosphorus concentration that is subsequently related to the average summer chlorophyll-a concentration. Chlorophyll-a is an indication of the planktonic algal biomass in the lake and is directly proportional to the phosphorus inputs. From the chlorophyll calculation one can calculate the lake clarity or Secchi disk transparency. Finally, the maximum permissible artificial loading that will not lower water quality in terms of chlorophyll-a or water clarity can be estimated. This maximum is expressed as the maximum of allowable development units (i.e., number of cottages).

This model is designed to predict the capacity of a lake for development without utilizing actual water quality data. In the case of Webster Lake, however, substantial data exists because of the cooperative volunteer lake assessment program between the lake association and the Biology Bureau. This existing data allows us to verify the results of the model. By utilizing the chlorophyll criteria of 5.0 mg/m^3, which is the average level currently measured in the lake, the model indicates that the existing phosphorus load approximates the permissible load, and that no further development should occur. This result suggests that the input data used is accurate. To maintain the present chlorophyll level in Webster Lake, either no further development should occur, or existing phosphorus sources must be reduced.

Table IX - 9 lists the input data utilized in the model while Table IX - 10 presents the model results using 5 mg/m^3 as the chlorophyll criterion. A chlorophyll of 5 mg/m^3 is a reasonable goal for Webster Lake. A chlorophyll level of 5 mg/m^3 is usually aesthetically acceptable, based on water quality considerations, to the average lake user. However, to give the Franklin Planning and Zoning Boards an idea of the consequences of future developments, two additional model scenarios were completed. A chlorophyll criterion of 6 mg/m^3 would allow 67 additional permanent homes, and a chlorophyll criterion of 7 mg/m^3 would allow 114 new permanent homes. The number of homes would change if a larger number of seasonal dwellings were substituted for some of the permanent homes. Each unit increase in chlorophyll results in an approximately 1 1/2 foot decrease in water clarity. An increase in chlorophyll from 5 to 7 mg/m^3 could reduce the water clarity of Webster Lake from current 13.5 to 10.5 feet.

Table IX-9

PREDICTING THE CAPACITY OF A LAKE FOR DEVELOPMENT

version 5.0

software by GLITCH

Morphology	Lake 1	Lake 2	Lake 3	Lake 4	Lake 5
	WEBSTER LAKE	HIGHLAND LAKE			
Surface area(m2):	2477500	856600			
Mean Depth(m):	5.7	6.5			
Volume(m3):	14053500	5510500			
Drainage Area(m2):	45066000	13236000			
Direct Drainage A:	31830000	13236000			
Flushing Rate:	1.50	1.20			
P retention coeff:	0.58	0.59			
Present Development (dwellings)					
Year-round Homes:	80	51			
Seasonal Homes:	157	32			
Weekend Camps:	0	2			
Campgrounds:	0	0			
Campers & Staff:	0	0			
Present Development (capita-yrs/yr)					
Year-round Homes:	320	204			
Seasonal Homes:	157	32			
Weekend Camps:	0	1			
Campgrounds:	0	0			
TOTAL CAPITA YEARS/YR	477	237			
Selected Export Coefficients (mg/m2/yr)					
Natural:	10.20	10.20			
Residential:	0.63	0.63			
Sub-Watershed Supply (kg/yr)					
Natural:	510.5	199.3			
Residential:	300.5	149.0			
Total:	811.0	348.3			
Downstream:	340.6	142.8			

Table IX-10

PREDICTING THE CAPACITY OF A LAKE
FOR DEVELOPMENT
version 5.0

software by GLITCH

Lake: WEBSTER LAKE

	Natural Supply	Artificial Supply	Total Supply
Direct:	510.5	300.5	811.0
Upstream:	81.7	61.1	142.8
	-----	-----	-----
Total:	592.2	361.6	953.8

Chlorophyll-a Criteria: 5.0 mg/m3
Permissible Supply: 935.4 kg/yr
Response time(yrs): 0.6-1.1

>>>>>>>>>><<<<<<<<<<<<
ALLOW NO FURTHER DEVELOPMENT: Total Supply > Permissible Supply